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Physico-chemical characteristics of topsoil for contrasted forest, agricultural, urban and industrial land uses in France

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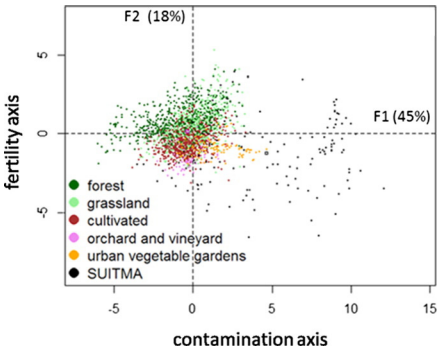
HIGHLIGHTS

- A database of caracteristics of 2451 topsoils representative for France is analysed.
- Human activities increase metal contamination along an anthropisation gradient.
- Total Cu, Pb, P_{Olsen} and pH are indicators of soil quality discriminated by land use.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil quality is related to soil characteristics such as fertility and contamination. The aim of this study is to assess the effect of land use on these soil characteristics and to confirm the following anthropisation gradient: (i) forest, (ii) grassland, (iii) cultivated, (iv) orchard and vineyard, (v) urban vegetable garden, and (vi) SUITMA (urban, industrial, traffic, mining and military areas). A database comprising the characteristics of 2451 soils has been constituted. In order to compare the topsoils from six contrasting land uses, a principal components analysis (PCA) was performed on nine geochemical variables (C, N, pH, P_{Olsen}, total Cd, Cu, Ni, Pb, Zn). The first axis of the PCA is interpreted as a global increase of topsoil metallic elements along the anthropisation gradient. Axis 2 reflects the variability of fertility levels. Human activity increases the pressure on soils along the proposed gradient according to six different distribution patterns. This better knowledge of topsoil quality and its dependence on current land use should therefore help to manage and preserve the soil mantle.

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1. Introduction

The quality of a soil is defined as its ability to fulfill functions and provide ecosystem services (Morel et al., 2014). Anthropisation, which designates an effect resulting from "human activity" (El Khalil et al., 2013), is often described as the main driver of ecosystem modifications (Vitousek et al., 1997), especially for biotopes like soil. The fertility level and contamination of soils are generally considered to be two aspects of soil quality. The modifications of the soil characteristics are dependent on the human use of land. Land use concerns the products and/or benefits obtained from use of the land, as well as the land management carried out by humans to produce those products and benefits (Ellis and Pontius, 2012). In this study, we will employ the term "land use" to describe the main type of human activity in each area. Land use involves the management and the modification of the natural environment through cultivation, urbanisation or industrialisation (El Khalil et al., 2013), which differ with the intensity and the duration of human impact (Morel et al., 2005a, 2005b). Urban soils differ from those in rural areas by the scale and intensity of human impacts on soils (Bullock and Gregory, 1991). Agriculture and forestry are often considered as having little disturbing effects on soil, whereas urban and industrial activities could potentially involve organic and inorganic pollution causing a significant alteration of physical, geochemical, and biological properties (Norra et al., 2006; Schwartz et al., 2001). In previous studies, Cd and Pb contaminations were often observed in community gardens or kitchen gardens (Douay et al., 2008; Mitchell et al., 2014). Urban soils are often characterised by high pH values as well as a large amount of coarse materials and soil organic matter, which influence porosity dynamics (Nehls et al., 2006). Therefore, all land uses do not have the same effect on soil quality. These effects vary in function of the frequency and intensity of corresponding human activities. Also, the ability of soils to provide such functions as vegetation and biodiversity support, filter and exchange, is modified by land use. However, to our present knowledge, no study has explored how a complete range of contrasting land uses influences topsoil chemistry. Saby et al. (2009) and Arrouays et al. (2011) have investigated the spatial patterns of the topsoil characteristics, but their work mainly focused on forest, agriculture and permanent crops. In contrast, the aim of this work is to establish the status of topsoil quality and its factors throughout France along an original land use gradient. According to the differences in intensity and frequency of human activities, we propose to test the existence of a soil anthropisation gradient from forest–grassland–cultivated–orchard and vineyard–vegetable urban garden to SUITMA (urban, industrial, traffic, mining and military areas). SUITMA are the ultimate members of a continuum characterised by increasing human influence, ranging from soils not or only slightly affected by human influence to agricultural lands to urban soils where the human imprint is maximum and where natural features have often disappeared (De Kimpe and Morel, 2000). The SUITMA group comprises soils used for the mining industry, solid and liquid waste dumping, as well as habitation and road construction. It should also be mentioned that garden soils are excluded here from the SUITMA category and constitute a separate land use. Indeed, there is no consensus about garden soils, which are often considered as cultivated soils with intensive management (e.g. McDonald and Balasko, 2003). For this study, rural gardens, rural market gardens, ornamental gardens and kitchen gardens have been skipped, and thus only urban vegetable garden soils from allotments have been considered.

Thanks to the existence of the national soil quality monitoring network based on a systematic grid over the entire French metropolitan territory (RMQS), the French national survey of garden soils (JASSUR-ANR) and data collected over 20 years on SUITMAs at the LSE research unit (Laboratoire Sols et Environnement, UMR 1120 University of Lorraine-INRA) (Lefort, 2009; Lefort et al., 2006), a comparative study of topsoil characteristics (pH, carbon (C) and nitrogen (N), available phosphorus (P_{Olsen}), and total trace metals) is put forward to assess the anthropisation gradient, using a multivariate statistics methodology. Our objective is to confirm the increase in total element concentration with the intensification of human activities along an anthropisation gradient. As for the fertility parameters in agricultural soils, two possibilities are considered: (i) an increase due to the use of fertilisers for plant biomass production, or (ii) a decrease induced by cultivation. We also hypothesise that even though the different data sets have quite distinct distributions, it is feasible to handle and interpret soil data in order to obtain further knowledge about soil quality depending on land use. The global characteristics of French topsoils will be discussed and compared according to land uses, without accurate agronomic interpretations and without taking into account successive land uses at a given point. The resulting implications for the development of soil quality indicators and for the management of French soils according to land use, will be discussed.

2. Materials and methods

The data pertain exclusively to the characteristics of topsoils (up to 30 cm) and do not concern deeper layers of soil profiles. The proposed gradient refers to varying land use: forest–grassland–cultivated–orchard and vineyard–urban vegetable garden–SUITMA (urban, industrial, traffic, mining and military areas). The first five land uses proposed in this gradient are exclusively dedicated to plant growth, although the last land use includes several human activities which could possibly impact plant biomass production.

2.1. Soil characteristic dataset

The dataset of 2451 topsoils has been built by gathering together data collected in the framework of distinct research programs carried out with different sampling strategies (Table 1). The different sampling approaches were developed in order to collect soil samples representative of French soils.

2.2. RMQS

The RMQS database (Arrouays et al., 2002) primarily consists of 2146 observations of soil properties on a 16-km regular grid across the 550,000 km^2 French metropolitan territory. If it was not possible to sample the selected site (e.g. in urban areas, in rivers or on roads) an alternative adjacent cultivated or undisturbed location within a 1-km radius was selected. Where this was not possible, the cell was omitted from the survey. This baseline survey of the RMQS was completed in 2009. At each site, 25 individual core samples were taken from the topsoil (0–30 cm) layer, using an unaligned sampling design within a 20 × 20-m area. The 0–30 cm layer was chosen to ensure consistency with existing surveys and because in France 30 cm is the maximum depth at which topsoil is generally affected by plowing. Core samples were bulked to obtain a composite sample for each site.

2.3. Garden soil database: JASSUR research program

The garden soils database exclusively concerns vegetable gardens from allotment sites. An allotment site contains several gardens, each

Table 1
Main features of collected soils.

Research program	Land use	Number of sampling points
RMQS	Forest	582
RMQS	Agriculture-grassland	623
RMQS	Agriculture-cultivated	820
RMQS	Orchard and Vineyards	48
JASSUR	Urban vegetable gardens	104
LSE database	SUITMAs	274
Total		2451